is only one component (HEPA filter, prefilter, etc.) per stage, as opposed to a bank installation in which there are two or more components per stage.

Single-path systems. A single-path system is one in which the total installed capacity of the air cleaning system is installed in a single air cleaning unit.

Segmented systems. A segmented system is a parallel configuration in which the installed capacity necessary to meet system design airflow requirements has been subdivided into two or more parallel air cleaning units.

Branched systems. A branched system is a parallel configuration with a common entrance duct or inlet, a common discharge duct, or both.

Isolatable units/components. An isolatable unit is an air cleaning unit that can be isolated from other units that comprise the system via dampers, backflow preventers (dampers), fan location, or system layout, and also can be operated simultaneously with, or alternatively to, the other units that comprise the system.

Compartment units. A compartmented unit is an air cleaning unit in which stages of components are installed in individual compartments in series.

2.5.3 MULTISTAGE FILTRATION

Series Redundancy. In highly contaminated areas and/or applications such as fuel processing and reprocessing plants, redundant systems are recommended for primary and secondary confinement. Their purpose is to increase the reliability of the system by providing backup filtration in the event of damage, deterioration, or a failure in the first-stage filters. Each stage of filtration (each filter bank) must be individually testable to claim credit for redundancy.

Increased Decontamination Factor. A HEPA filter by definition, has a minimum efficiency of 99.97 [Decontamination factor (DF) = 3333] for 0.3-μm particles. DFs of at least 10^{11} are recommended for plutonium in gaseous effluents. Although some decontamination is effected by plant operations, the greatest portion must come from the HEPA filters, which means that two, three, or even more stages of HEPA filters may be necessary.

In theory, the DF of a multistage HEPA filter installation will be $DF_f^{\,n}$ where DF_f is the DF of a single HEPA filter stage (3333) and *n* is the number of stages. Consideration should be given to assigning a reduced decontamination factor for the secondary stages. Actual DFs may be reduced in secondary stages possibly due to the lower upstream concentration of contaminants, upset conditions, or deterioration and aging of the HEPA filters. For purposes of assigning safety credit in facility safety reports, a conservative decontamination factor should be used.

2.6 OPERATIONAL CONSIDERATIONS

2.6.1 MODE OF OPERATION

According to operational requirements, an air cleaning system may be operated full-time or part-time, or simply be held in standby for emergency service. If processes in a building are operated only one or two shifts a day, the designer may have a choice between continuous operation and operation only during those shifts. The designer must evaluate the effects of daily starts and stops on the performance and lifetimes of filters and other components versus the higher power and maintenance costs that may be incurred by continuous operation. Experience has shown that, all factors considered, continuous operation of air cleaning facilities, perhaps at reduced flow during weekends and holidays, is generally the most satisfactory mode of operation for buildings in which radioactive operations are conducted. Unless ducts, filter housings, damper frames, and fan housings (i.e., the pressure boundary) are extremely leaktight, out-leakage of contaminated dust into occupied spaces of the building may occur during shutdown periods.

Many facilities require standby exhaust or air cleanup systems that are operated only in the event of an emergency or for periodic testing. When designing standby systems, the engineer must keep in mind the possibility of corrosion and filter and adsorber deterioration even when the system is not in use.

In commercial nuclear power plants, air cleaning systems are either continuously operated (since the facility is continuously producing electrical power) or are standby systems.

2.6.2 MOISTURE SEPARATORS

Moisture separators are used when moisture is present in the air stream and must be removed before further filtration occurs. Moisture separators need to be periodically inspected for buildup of dust and dirt that could hinder their moisture removal effectiveness and increase their pressure drop. They are usually made of materials that can be washed to remove dust and dirt. After washing, care should be exercised to be sure they are dry before placing them back into the air cleaning unit. Moisture separators should meet the requirements of ASME AG-1, Section FA[30]

2.6.3 SUPPLY-AIR FILTERS

Atmospheric dust brought into the building with ventilation air constitutes a substantial fraction of the dirt load in the building and the dust load in the exhaust air cleaning system. Removing this dust before it gets inside the building provides the double advantage of protecting the exhaust filters from premature dust loading and reducing janitorial and building maintenance costs. When operations within a building do not generate heavy concentrations of smoke, dust, or lint, it may be possible to substantially reduce the dust loading in the exhaust system by providing medium-efficiency (50 to 90 percent ASHRAE efficiency)[15] building supply-air filters, thereby shifting much of the burden of what would otherwise be a change of "hot" (radioactive) prefilters in the exhaust system to a more economical change of "cold" supply-air filters. The labor costs involved in replacing "cold" filters is a small fraction of those for replacing "hot" filters.

Noticeable reductions in janitorial costs have been observed in several DOE installations after changing to higher-efficiency building supply-air filters. There is also a trend toward using better building supply-air filters in commercial buildings. One operator of a commercial office building reported that the time interval between major cleaning and repainting had doubled after replacing his original panel-type furnace filters with 60 percent ASHRAE-efficiency filters.[16]

Louvers or moisture separators or both must be provided at the air inlet to protect the supply filters from the weather. Rain, sleet, snow, and ice can damage or plug building supply-air filters, resulting not only in increased operating costs, but also upset of pressure conditions within the building and possible impairment of the more critical exhaust air cleaning system. Heaters are desirable in the building supply system even in warm climates. Icing has caused severe damage to building supply-air filters at a number of DOE installations, even in the South. Screens should be provided over supply-air inlets located at ground- or roof-level to protect inlet filters and demisters from grass clippings, leaves, dirt, and windblown trash. If possible, inlets should be located well above grade or adjacent roofs so they are not exposed to such materials.

2.6.4 MEDIUM-EFFICIENCY FILTERS

Medium-efficiency filters are installed either locally at the entrances to intake ducts, in air cleaning systems, or as protection for other equipment such as heating and cooling coils. When used to extend the life of HEPA filters, they are commonly referred to as "prefilters." Intake or duct-entrance medium-efficiency filters minimize dust accumulation in ducts, thereby reducing a potential fire hazard. Medium-efficiency filters located upstream of heating or cooling coils protect the coils from dust and dirt accumulating on their tubes and fins, which would adversely affect the performance (heat transfer) of the coil.

A typical increase in HEPA filter life through the use of prefilters is illustrated in **FIGURE 2.7**. The increase for a specific application depends, of course, on the quality of the prefilter selected and the nature and concentration of dusts and particulate matter in the system.

Generally speaking, medium-efficiency filters should be provided when the potential dust concentration in the air leading to the air cleaning system exceeds 10 grains per 1,000 ft^3, and should be considered if the dust concentration exceeds 1 grain per 1,000 ft^3. The use of prefilters is recommended in ESF systems for nuclear reactors.[18] The filters must meet the design and qualification requirements of ASME Code AG-1 Section FB[30] to ensure that air cleaning system integrity is maintained. The decision to install prefilters should be based on the need to provide

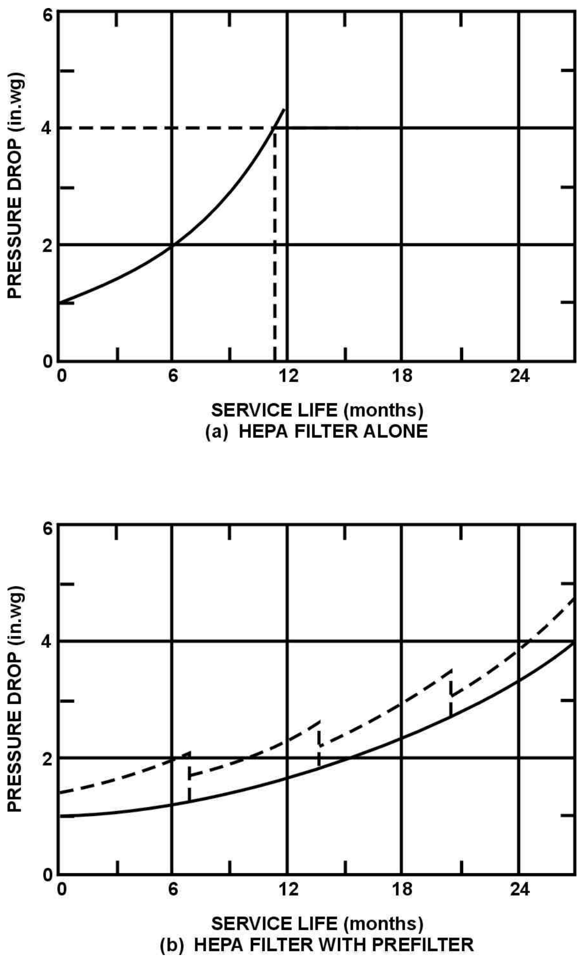

Figure 2.7 – Comparison of HEPA filter life with and without prefilter

the best operational balance between HEPA filter life, with its attendant decrease in HEPA filter change frequency, and the procurement and maintenance costs for the prefilters.

Medium-efficiency mounting frame design should be in accordance with ASME Code AG-1, Section FG.[30] Housing design should also be in accordance with ASME AG-1 Code, Section HA.[30]

2.6.5 HEPA Filters

HEPA filters are intended primarily for removal of submicrometer particles and should not be used as coarse dust-collectors. They have relatively low dust-holding capacity, particularly for large particles and lint, and may plug rapidly when exposed to high concentrations of such material or smoke. Lint may tend to bridge the pleats of the filter, even further reducing its capacity. The HEPA filter is also the most critical particulate-removal element in the air cleaning system from the standpoint of preserving containment, and its failure will result in failure of system function.

HEPA filters should not be placed back-to-back with any other component of the air cleaning unit, either upstream or downstream. Adequate space must be provided for leak testing, maintenance, and replacement of these filters. ASME Standard N509[23] contains recommendations for the amount of space required between components for adequate testing, maintenance, and replacement. HEPA filters should meet the requirements of ASME AG-1, Section FC[30]

2.6.6 Adsorbers

Adsorbers are required for removal of radioactive iodine and iodides. ASME Code AG-1[30] provides the design, construction, and testing requirements for the four types of adsorbers (see Chapter 8 for a detailed discussion of adsorber design and function):

- Type I "V-bed" design, usually rated at 500 cfm with a 1-in. bed thickness and a residence time of less than 0.12 sec
- Type II "Tray Type" design, a carbon cell rated at 333 cfm with a 2-in. bed thickness and a 0.25-sec residence time
- Type III "Gasketless Adsorber" design, a fill-in-place module rated for system flow with a bed thickness of 2, 4, 6 or 8 in., depending on the required system residence time
- Type IV "U-bed" design, rated at 500 cfm with a 1-in. bed thickness and a residence time of less than 0.12 sec (same rating and residence times as the Type I design)

2.6.7 Particulate Filter Change Frequency

The principal costs of operating a high-efficiency air cleaning system are power (e.g., for fans), replacement filters and adsorbers, and labor. The principal factor that affects these costs is the frequency of filter changes. Replacement filters and adsorbers and the labor costs to install and test the filter system in-place after installation of replacement filters may make up as much as 70 percent of the total cost of owning a system (including capital costs) over a 20-year period. Power accounted for only 15 percent of total owning costs in a study made by the Harvard Air Cleaning Laboratory.[14] Measures such as use of high-efficiency building supply-air filters, use of prefilters ahead of HEPA filters, operation of the system below its rated airflow capacity, and operation of HEPA filters until they have reached high airflow resistance before replacement all tend to decrease filter change frequency and thereby reduce costs. Caution should be exercised when establishing filter change frequency. Filters can become loaded with radioactive particles or reach an age when replacement is warranted even though they may not be dust/dirt-loaded to a point that indicates change-out is necessary due to pressure drop.

It should be noted that, for systems governed by commercial nuclear power plant technical specifications, strict requirements for operating filters at maximum pressure drops is specified. Therefore, filters should not be operated at maximum pressure drop; they must always be ready with enough remaining capacity to handle the loading that can be expected from a design basis event.

Lawrence Livermore National Laboratory recently developed the requirement that HEPA filters be replaced ten years after the date of manufacture. Exceptions to this requirement include:

- Any filter that has become soaked or could have become soaked (e.g., as a result of an in-duct water sprinkler's activation or water spraying directly on the filter) must be replaced promptly.
- Any filter that could become soaked (e.g., as a result of an in-duct water sprinkler's activation) must be replaced within five years of the date of manufactur.[56]

The underlying rationale for this set of requirements is found in Bergman's *Maximum HEPA-Filter Life*.[58]

2.6.7.1 Prefilters for Non-ESF Applications

Some prefilters can be operated to higher pressure drops than recommended by their manufacturers. This results in less frequent prefilter changes than when prefilters are changed at a pressure drop of only two or three times the clean-filter pressure drop, as recommended by most manufacturers. Care must be taken in selecting prefilters. Because of the many types, efficiencies, configurations, and constructions available, the designer must specifically investigate the safe overpressure allowance for the particular model under consideration. **FIGURE 2.8** clearly shows the results of overpressuring prefilters. In the case shown, the problem of filter blowout was overcome by working with the manufacturer to reinforce the filter itself. Some benefit could also have been obtained by installing a screen or expanded metal grille on the downstream face of the prefilters against which the filter cores could bear; in any event, screens or grilles would have prevented damage to the HEPA filters when pieces of prefilter struck them.

Figure 2.8 – Results of overpressuring prefilters

2.6.7.2 HEPA Filters for Non-ESF Applications

Most HEPA filter manufacturers' literature suggests replacement of HEPA filters when the resistance due to dust loading has reached 2 in.wg. By specification, however, HEPA filters designed and manufactured to the requirements of ASME AG-1, Section FC,[39] are capable of withstanding a pressure drop, when clean, of at least 10 in.wg without structural damage or reduction of efficiency.[19] When other factors such as radioactivity and fan capacity do not have to be considered, replacement at a pressure drop of only 2 in.wg is considered under-utilization of the filter. At many DOE facilities, HEPA filters are operated routinely to pressure drops as high as 4 to 5 in.wg. **FIGURE 2.9** shows the effect of such operation on filter life and maintenance costs.

The advantage of operating to high-pressure drop must be weighed against first costs (higher-static-pressure fans, larger motors, heavier ductwork), higher power costs, and less efficient fan operation. The installed fan and motor must have sufficient capacity to deliver the design airflow at the maximum differential pressure under which the system will operate, with the filters at maximum dirty-filter pressure drop prior to change. Therefore, consideration must not only be given to the increased installed capacity required to operate to the higher pressure drop, but also to the fact that the fan operates at a penalty much of the time to provide the required airflow over the wide span of pressure drop between installation and replacement of filters.

The cost of ductwork, on the other hand, may not be significantly affected by operation to a high pressure drop because there is a minimum sheet-metal thickness for effective welding, regardless of pressure. The cost of fans and motors is a function of the maximum total pressure that must be developed. Fan hp can be estimated from the following equations.[19]

$$hp_f = \frac{Q\,\Delta p}{6356 E_f} \qquad (2.1)$$

where:

hp_f = fan hp

Q = system airflow, cfm

Δp = maximum pressure drop across air cleaning system, in.wg, at time of filter replacement

E_f = fractional efficiency of fan (0.60 usually assumed for estimating).

Motor horsepower can be estimated from the equation:

$$hp_m = \frac{hp_f}{E_m} \qquad (2.2)$$

where:

hp_m = motor horsepower

hp_f = fan horsepower

E_m = fractional motor efficiency (0.90 usually assumed for estimating for 20-hp motors and larger).

Although investment and power costs will be lower for systems operated to 2-in.wg pressure drop, the total annual cost of owning a system, including materials and labor costs for filter replacement, may be less for a system in which HEPA filters are replaced at pressure drops on the

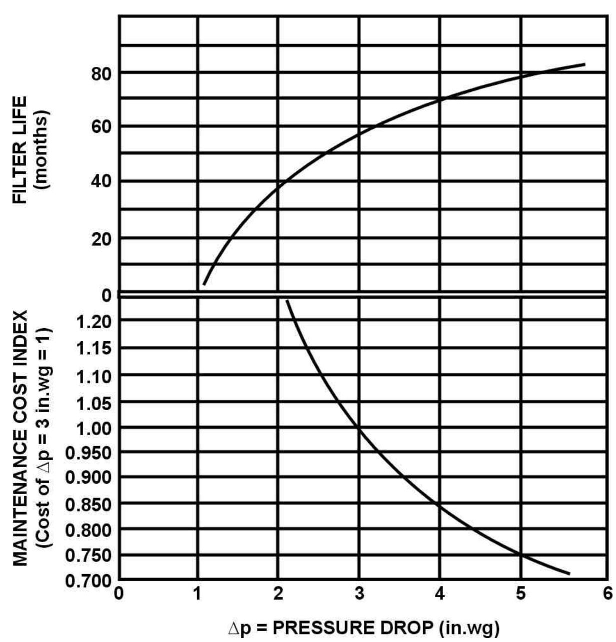

Figure 2.9 – Effect of operating HEPA filters to high-pressure drop on filter life and maintenance cost (including replacement filters and labor)

order of 4 to 5 in.wg. Total savings for the facility as a whole may be even greater when the reduced interruption of building operations due to the reduced frequency of filter change is taken into consideration.

2.6.8 ADSORBER CHANGE FREQUENCY

Adsorbers are periodically tested for their ability to retain the necessary capacity to remove radioiodine from the air or gas stream. Laboratory testing is required in accordance with the requirements of ASME Standard N510.[34] The plant technical specifications and Regulatory Guides govern the frequency of testing for commercial nuclear power plants.

Another factor that must be considered is the fact that the adsorbent will age (or "weather"). That is, the adsorbent will gradually deteriorate over time due to a reduction of the number of "active sites" as a result of oxidation of its surfaces or to desorption or chemical reaction of its inpregnant. The basis for adsorbent change frequency, therefore, should be laboratory test results with a reasonable limit applied for aging. Charting test results versus time should enable the air cleaning system operator to reasonably predict when change-out of the adsorbent will be required. Upset conditions such as a solvent release or moisture contamination will affect the prediction.

2.6.9 SIZING AND RATING

Underrating. The service of all internal components (except moisture separators) can be extended, and system pressure drop for a given level of dust loading can be reduced by underrating, i.e., by oversizing the system and installing more filter and adsorber capacity than required to meet system design airflow needs (based on the nominal airflow rating of the components). **FIGURE 2.10** shows that the increase in filter life obtainable by underrating is roughly proportional to the square root of the degree of underrating. A study by the Harvard Air Cleaning Laboratory[14] suggests that the economic limit of underrating is about 20 percent (i.e., system design airflow equal to 80 percent of installed airflow capacity).[14]

Overrating. Operation of a system at airflows greater than the installed airflow capacity of the

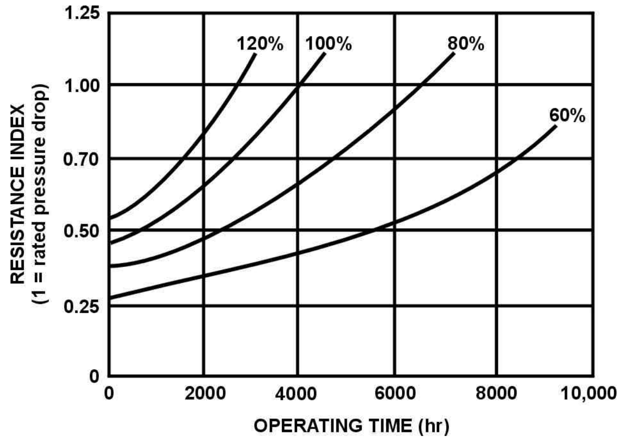

Figure 2.10 – Effect of underrating on service life of extended-medium filters, based on percentage of manufacturer's rated filter airflow capacity

system should be avoided, particularly in systems with radioiodine adsorbers whose performance depends on the residence time of air within the adsorbent bed. When airflow rates exceed the rated airflow capacity of HEPA filters, filter life decreases more rapidly than the equivalent increase in flow rate, as can be seen from the 120 percent curve in FIGURE 2.15. As noted above, the residence time of contaminant-laden air in adsorber units is inversely related to airflow rate. Overrating of these units decreases their ability to trap gaseous contaminants, thereby degrading their function.

2.6.10 UNIFORM AIRFLOW DESIGN

In large air cleaning systems, because of the stratification of airflow due to poor transitions between ducts and housings, or between housings and fans, or because of poorly designed housings, filters or adsorbers at the center of a bank may receive higher airflow than those on the periphery of the bank. This not only results in nonuniform dirt loading of filters but may also result in excessive penetration of those HEPA filters closer to the air intake if the degree of airflow nonuniformity is great. **FIGURE 2.11** shows that penetration of HEPA filters by very small particles is directly velocity-dependent and increases significantly at very high airflow rates. Conversely, penetration of HEPA filters by particles larger than 1 μm may increase at very low flow rates due to the reduction in effectiveness of the impaction mechanism on which trapping of those particles

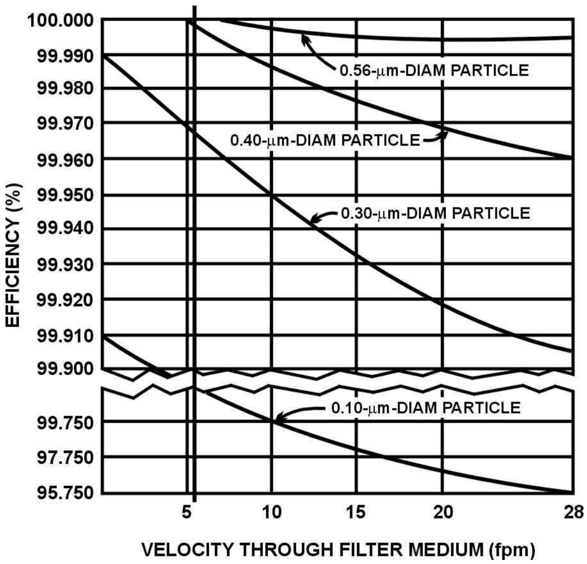

Figure 2.11 – Penetration of HEPA filter medium by submicron particles as function of flow rate through the medium

depends. If some filters are operating at very high airflow and some at very low airflow, as could happen in a poorly designed housing and filter bank, it is possible that significant penetration could occur even though the filters are in good condition. Low flow rates improve the efficiency of radioiodine adsorbers, but high flow rates decrease efficiency, as discussed in 2.6.9. Therefore, significant nonuniformity of airflow through a bank of adsorber cells can reduce the overall efficiency for trapping radioactive gases of interest. Figure 4.28 shows a well-designed duct-to-housing transition that will produce satisfactory airflow distribution through the banks of filters and adsorbers.

Filter housings can be obtained with built-in devices to assist in generating uniform up- and downstream flow distribution using Stairmand disks and similar devices. These make testing faster and more accurate, and minimize those occasions when personnel must enter the filter housing (a confined space) for any reason.

2.6.11 MAINTAINABILITY AND TESTABILITY

Maintenance and testing are two operational factors whose cost can be minimized by good initial design and layout of ventilation and air cleaning systems. Inadequate attention to maintenance and testing requirements at the initial phase of the project can result in much higher operating costs. Design of air cleaning systems in accordance with ASME AG-1[30] will result in optimum maintainability and testability. Two elements that largely influence the costs of these functions are the accessibility of components requiring periodic test and service and the frequency of filter and adsorber replacement. In systems that involve handling of radioactively contaminated filters and adsorbers, the frequency of changing these components and the time required to accomplish the change can be especially critical, because the total integrated radiation dose a workman can be permitted to receive in each calendar period is limited. Maintenance and testing of radioactively contaminated and other highly toxic systems are much more costly than the same operations in nonradioactive systems because of the time required for personnel to change into and out of protective clothing; to decontaminate and clean-up the area, tools, and equipment after the operation; to dispose of contaminated filters (a significant cost itself); and to bathe and be monitored by health physicists.

In addition, extra attention must be given to filter or adsorber cell installation (compared with common air filters, for example). If the system does not meet the test requirements of ASME AG-1, Section TA,[30] after the change, then rework must be performed until the problems are found and corrected. There is also a need for health physics monitoring before, during, and after all maintenance operations. The fact that personnel have to work in protective clothing, including respirator or full-face respirator, also adds to the time required. Regardless of these inherently high time and money costs, proper maintenance and testing are primary factors in ensuring the reliability of the air cleaning system, and they cannot be done properly unless the facilities have been properly designed and built.

Frequency of Maintenance and Testing. Measures that reduce the frequency of filter (HEPA and prefilter) and adsorber replacement also reduce system costs and downtime. Several of the factors discussed earlier—the use of good building supply-air filters and prefilters and underrating—serve to extend component life and reduce the frequency and cost of service. Exhaust system HEPA filter and adsorber installations must be tested to the requirements of ASME AG-1, Section TA,[30] after each component change so that any extension of service life also directly reduces testing costs. [Note, however, that regulatory bodies often dictate frequency of testing.]

Accessibility. When laying out ventilation and air cleaning facilities, the designer must consider the location of fans, dampers, instruments, and filter housings, as well as the working space adjacent to them; working space and spacing of banks within man-entry housings; height and array of filter and adsorber banks; and routes to be used for moving new and used filters and adsorbers between storage, installation, and disposal areas. Where Type III adsorbers are used, it is imperative to provide space and routing (from the storage location to the air cleaning unit) for the adsorber fill-and-drain apparatus. This apparatus is a large piece of movable equipment. In addition, space for drums of adsorbent must be provided because they are used in conjunction with operation of the fill-and-drain apparatus. Note that the fill method must be qualified to ensure adequate packing density. Hand filling is not acceptable. Failure to provide adequate space in and around housings and mechanical equipment (fans, dampers, etc.) results in high maintenance and testing costs, inhibits proper care and attention, creates hazards, and increases the chance for accidental spread of contamination during service or testing operations. Recommendations for arrangement and space requirements for air cleaning components should be in accordance with ASME N509.[23] Even greater space requirements are needed for remotely maintainable systems.

Ease of Maintenance and Testing. Simplicity of maintenance and testing is a primary factor in minimizing the time personnel must remain inside a contaminated housing and restricted areas of a building during a filter or adsorber change or test. Therefore, it is an important factor in reducing both personnel exposures and costs. The following strategies will help ensure simplicity of maintenance and testing.

- Filter housings should be laid out and designed in accordance with ASME AG-1[30] and ASME N509[23] to ensure quantitative tests can be performed and to minimize reaching, stooping, and the use of ladders or temporary scaffolding for gaining access to filter or adsorber cells. Some reaching and stooping are unavoidable in man-entry housings, but it should not be necessary for personnel to perform physical contortions or climb ladders to remove and replace filters in single-filter installations. Similarly, in bank systems, it should not be necessary for workmen to climb ladders or temporary scaffolding to gain access to the upper tiers of filters or adsorbers. If this is unavoidable, then permanent ladders and platforms need to be built into the air cleaning housing. Personnel entries into housings should be minimized. These are, at best, confined spaces that require permits for access and have contaminated surfaces that require additional, potentially costly and difficult precautions.
- Racks (frames) should be designed to the requirements of ASME AG-1, Section FG,[30] and ASME N509[23] to ensure proper spacing between components for maintainability and testability.
- Electrical, water, and compressed air connections should be available nearby, but in no case should they be located inside the filter house.
- Materials-handling equipment should be employed, including dollies for moving new and used filters and adsorbers, hoists or other means of handling the heavy adsorber cells in systems containing these components, and elevators or ramps for moving loaded dollies up and down within the building.
- Filter housings should be located inside the building. It is undesirable for personnel (1) to conduct a filter change or test out of doors where wind or rain may cause a spread of contamination, (2) to cross a roof to gain access to a filter housing, or (3) to wait for good weather to carry out a scheduled filter or adsorber change or test. Weather damage and corrosion are always possible, especially with wood-framed filters.
- Decontamination and clothing-change facilities (including showers) should be located nearby.

- Maintenance and testing (per ASME AG-1, Section TA,[30] ASME N510,[34] and plant maintenance procedures) should be well planned and rehearsed. This is particularly important to keep radiation exposure for workers at ALARA levels.

Construction. Designing for maintainability requires careful attention to the details of construction, including tolerances, surface finishes, and the location of adjacent equipment and service lines. Ducts and housings should have a minimum number of interior ledges, protrusions, and crevices that can collect dust or moisture, impede personnel, or create a hazard in the performance of their work. Provision of relatively high-efficiency (40 to 90 percent ASHRAE) prefilters at duct inlets will minimize the accumulation of dust and contamination in the ducts. If these are not provided, easily opened ports and hatches for inspection and cleaning must be provided at strategic and accessible locations in the duct. Duct runs should have enough mechanical joints to permit easy erection and dismantling. Otherwise, replacement of radioactively contaminated ducts can be an expensive and hazardous job.

Housings, ductwork, and component-mounting frames must be able to withstand anticipated system pressures and shock loadings without distortion, fatigue, or yielding that permits in-leakage or bypassing of the filters or adsorbers. These components must meet a pressure test in accordance with the requirements of ASME Standard N509[23] and ASME AG-1.[30]

Interior surfaces and finishes warrant special attention. Regardless of the formulation when coatings are used, a primary factor in a long, dependable service life is proper preparation of the surface to be coated. Manufacturers coating or paint instructions and plant procedures must be followed precisely. One alternative to the coating requirements is to build the housings and housing components from stainless steel or other harsh-environment-resistant materials. This reduces the need for frequent and costly repair to coatings that are damaged as a result of routine testing and maintenance.

2.6.12 INSTRUMENTATION AND CONTROL

General Information. Instruments and controllers are used to monitor and control process air streams. They measure and modulate temperature, relative humidity, pressure, vibration, current, and voltage. Recommended instruments for ESF and non-ESF systems are listed in ASME N509.[23] The design, construction, qualification, and testing of instruments and controls should follow the requirements of ASME AG-1, Section IA.[30] Also, ASME AG-1, Appendix IA-C,[30] contains guidance for the instrumentation and controls that should be provided for nuclear air and gas treatment systems.

ESF Air Cleaning Systems. All ESF air cleaning systems must have appropriate monitoring instruments, alarms, controls, and hand-switches located adjacent to the air cleaning unit, as well as redundant instruments, alarms, and hand-switches at remote control panels. The minimum requirements for an ESF system and components are given in ASME AG-1, Section IA.[30]

The location of sensing elements in ESF systems is critical to obtain accurate readings. ASME AG-1[40] and ASME N509[23] provide guidance and preferred locations for sensing elements and control and monitoring panels. Sensors must be located where they can provide a representative sensing pattern.

All instruments and controls, including sensing lines, tubes, and valves, must be seismically and environmentally qualified. One often overlooked item is the structural integrity of the tubing for the pressure gages and other instrument sensing lines. Since the instrumentation is normally routed to fit, the design must verify that the supports are adequate to meet the structural requirements. Drift, chatter, and other anomalies experienced during qualification may be acceptable in some applications, but not others. For example, minor contact chatter during testing of a relay may be acceptable for a control valve.

All instruments and devices should be calibrated and tested in accordance with the manufacturer's test procedures. In addition, all power wiring internal to control panels, except control or shielded cable, should be subjected to a high-potential test to demonstrate freedom from ground and correct wiring connections. In addition, extensive onsite pre-operational testing should be performed on all instruments and control systems associated with nuclear air cleaning systems prior to placing them in service to confirm correct installation and design and ensure operability.

The instrumentation and control systems associated with ESF air cleaning systems are intended to control the environment of the space served within the limits of the controlled variables and to monitor the performance of the system and its components to ensure safe, efficient, reliable operation. The design of instrumentation and control systems should consider the consequences of a single failure,2 [8] as well as prevalent environmental conditions.

The primary variables by which nuclear air-cleaning systems are controlled are airflow rate and pressure. Temperatures and radioactivity levels are also monitored to indicate system performance variables and to activate an alarm when abnormal conditions occur. Effluent air cleaning systems typically maintain minimum negative pressures, whereas habitability systems usually maintain a positive pressure in the space served.

Instrumentation should be provided to monitor the activity levels of all effluent discharges to the atmosphere, including airflow rate and concentrations of radioiodine, aerosols, and noble gases. Values in excess of established limits should trigger a local alarm and send an alarm signal to the main Control Room. Airflow rates and radioactivity levels for habitability systems should also be monitored and alarmed.

The best indicators of system performance for continually operating systems are radioactivity levels. Monitoring levels before and after air cleaning units indicates trends in filter degradation. In addition, controls should be provided to assist operators in monitoring system performance. Fire protection instrumentation should be based on the requirements of ASME N509[23] and the recommendations contained in Chapter 10.

2.7 SPECIAL CONSIDERATIONS

The special considerations discussed in this section are derived from experience gained in the design, construction, modification, and operation of nuclear facilities.

2.7.1 SEALING OF SPACES TO BE MAINTAINED AT A POSITIVE OR NEGATIVE PRESSURE DURING NORMAL/ACCIDENT MODES OF OPERATION

Many spaces of a commercial nuclear power plant require either a positive or negative pressure to be maintained between the space, the environment, and the adjacent spaces of the plant. Some examples are:

- Control Room
- Spent Fuel Pool
- Auxiliary Building/ECCS Pump Rooms
- Shield Building
- Technical Support Facility

Achieving this pressure differential requires special consideration of how well the spaces are sealed. Early in the design and construction of these areas, the need to properly seal them was not well understood by either the engineers or architects. As a result, when these areas/systems were placed in operation, the required pressure differential could not be achieved. Consequently, a great deal of backfit work had to be done to properly locate leak paths and develop and apply seals that would produce the required results. The following examples describe some of this backfit work.

Control Rooms. Control Rooms must be maintained at a positive pressure to ensure radiation is kept out of the Control Room during and after design basis events. Leaks were found around personnel entry doors, instrument and cable penetrations in walls and floors, cable penetrations under Safeguards Control cabinets, and ductwork penetrations. Remedies to these problems included replacement of some of the personnel doors with marine bulkhead-type doors and foaming large portions of walls and floors to seal around cable, instrument lines, and ductwork. Other personnel doors had to be fitted with leaktight seals to achieve the required pressurization. Rework, particularly foaming of penetrations, required several iterations to solve the leakage problems. In addition, many plants